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WASTEWATER SOLIDS PROCESS TECHNOLOGY FOR ENVIRONMENTAL QUALITY IMPROVEMENT

James E. Smith, Jr.

Federal Water Quality Administration
Cincinnati, Ohio

December 1970

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ABSTRACT

A review of problems confronted in disposing of sludges from municipal wastewater treatment plants is presented. The quantities and characteristics of these sludges that must be dealt with are enumerated. Waste sludges originating from the activated sludge and tertiary treatment processes together with alum sludges are typically high in moisture and gelatinous in nature and are shown to present the greatest challenge in dewatering.

Each of a variety of biological, chemical and physical treatment alternatives is discussed. Recently completed in-house research of the Ultimate Disposal Research Program, Advanced Waste Treatment Research Laboratory, Federal Water Quality Administration is noted. This includes the optimization of the aerobic stabilization process, the use of organic polymers and various inorganic additives including iron and sludge incinerator ash on sludge filtration and thickening. For some treatment plants sludge incinerator ash is an economical way of increasing the filter yield.

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Freezing of aluminum hydroxide sludges was demonstrated as an excellent means of concentrating and dewatering sludge when it could be done naturally in a cold climate, but artificial freezing is economically prohibitive.

Land spreading, strip mine reclamation, landfill, ocean disposal, and pipeline transport are discussed. The present economics of some processes are noted.

WASTEWATER SOLIDS PROCESS TECHNOLOGY FOR ENVIRONMENTAL QUALITY IMPROVEMENT*

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INTRODUCTION

Solids removed in the processing of waters for human consumption, industrial usage, or in the case of wastewaters, for discharge to a receiving stream, present a disposal problem which must be considered in the design of sanitary facilities. The disposal of sludges from wastewater treatment will today account for up to 50% of the total treatment cost.[1]

The purpose of this presentation is to discuss some alternative methods for treatment and ultimate disposal of sludges.

Sludge can be defined as the settleable solids that are naturally present in water and wastewater, or that are formed from nonsettleable matter by chemical coagulation and precipitation and by biological flocculation and precipitation. Sludge is a semi-liquid waste which flows, can be pumped, exhibits hindered settling characteristics, and is usually brown

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to black in appearance. Odors may or may not be present.

Tighter effluent criteria and the resultant construction of additional secondary facilities, increasing land scarcity, and population pressure have combined to make sludge disposal more difficult and expensive than ever before. While no "breakthroughs" in sludge disposal technology have occurred, new ideas for the treatment and disposal of sludges have been proposed or put into use in recent years. The results of this increased activity should be improved technology and lower costs for average sludge disposal.

The quantities of sludge produced in the treatment of wastewater by simple gravity sedimentation, chemical treatment and biological processes are shown in Table 1.

TABLE 1

TYPICAL QUANTITIES OF SLUDGE PRODUCED IN WASTEWATER TREATMENT PROCESSES

Treatment	Keefer[2]	Imhoff & Fair[3]	Babbitt[4]	M&E[5]
Plain Sedimentation	2,950	3,530	2,440	3,000
T F Humus	745	530	750	700
Chem. Precipitation	5,120	5,100	5,250	5,100
Activated Sludge	19,400	14,600	18,700	19,400

(Given as gallons/million gallons sewage treated)

The table shows that the least amount of sludge is produced by either simple sedimentation alone or in conjunction with a trickling filter. On the other hand, if chemical addition is

practiced or the activated sludge process is included in the processing sequence, large additional quantities of sludge must be handled, necessitating larger facilities.

SLUDGE CHARACTERISTICS

The moisture quantities of some typical wastewater treatment plant sludges are shown in Table 2. This table shows that the water content of all the sludges shown is high. Obviously additional treatment is needed before incineration can be considered. In the case of the primary, chemically precipitated and digested sludges, we see that 10 to 20 pounds of water are present for every pound of sludge solids. On the other hand, with the activated sludge and high rate trickling filter sludges we have as much as 50 pounds of water for every pound of sludge solids, making disposal much more difficult. It should be noted that sludge will burn without supplemental fuel if it is above 25-30% solids (Burgess, 1968[5A]). Therefore, approximately 3 tons of H_2O can be evaporated by each ton of dry solids burned. Table 3 illustrates once more that activated sludge has a high moisture content. As expected from its low solids content, its density is only slightly greater than the density of water. Further in Table 3 we see that up to 6 times as much activated sludge is produced for every million gallons of wastewater treated as compared with primary treatment.

TABLE 2

PERCENTAGE MOISTURE CONTENT
OF SOME TYPICAL SLUDGES

Treatment	% Moisture
a) Primary Sedimentation	95
b) Chemical Precipitation	93
c) Trickling Filters	
1. Humus - Low Rate	93
2. Humus - High Rate	97
d) Activated Sludge	98 - 99
e) Well Digested Sludge	
1. Primary Treatment	85 - 90
2. Activated Sludge	90 - 94

TABLE 3

CHARACTERISTICS AND QUANTITIES OF SLUDGES[6]

Treatment	%SS Rem	#/d/mg removed	Vm %	Sp Gr S/Solids	Moist %	Liquid Sp Gr	Sludge lbs/gal	Sludge gal/mg
Plain Sed.	60	1,020	65	1.33	95	1.013	8.45	2,410
Tr F Humus	30	510	45	1.52	93	1.025	8.55	852
Act. Sludge (excess)	92	1,563	65	1.33	98.5	1.005	8.36	10,700
Imhoff Tank Dig.	60	1,020	50	1.47	90	1.033	8.62	827

%SS Rem = Suspended Solids Removal
#/d/mg = Pounds/day/million gallons
Vm % = Percentage of volatile materials removed
Sp Gr = Specific Gravity

Just as important as the amount of water in the sludge is the ease with which the sludge solids and water can be separated. Unfortunately, the sludges with the highest water content -- the biological sludges -- are the hardest to dewater. Unless treated in some way, they cannot be economically dewatered.

SLUDGE MANAGEMENT ALTERNATIVES

The existence of a disposal problem is apparent. In selecting a disposal process, the pollution potential, aesthetics, and economics of the process must be considered. According to the National Environmental Policy Act of 1969 and Executive Order 11514, Protection and Enhancement of Environmental Quality, all Federally-assisted projects must conform to the following:

a. Planning for the proposed project must take into account all aspects of environmental quality protection. Efforts shall be taken to preserve natural beauty, wildlife, recreational areas, historic sites, and private property.
b. The project must be designed and constructed so as to have the least possible impact on the environment.
c. Attention must be given to the general aesthetic appearance of the facility and to the prevention of any possible odor problems.

d. Planning shall be coordinated with local planning and citizen groups to resolve potential site problems.

e. Plant locations on flood plains should be avoided whenever practicable. When such locations are unavoidable, adequate protection from flooding must be provided.

There are biological, chemical, and physical methods available to us, as shown in Figure 2.

BIOLOGICAL PROCESSES

In the biological treatment line we have: 1) Aerobic stabilization: 2) Anaerobic digestion: and 3) Composting.

AEROBIC STABILIZATION

Aerobic stabilization describes the separate aeration of waste primary and/or of secondary sludge. The biological steps occurring include: 1) the direct oxidation of any biodegradable matter by the biologically active mass of organisms: and 2) oxidation of microbial cellular material, endogenous respiration.[7] This process has aroused much interest where a demand for small treatment plants exists. Aerobic stabilization is simpler to operate than anaerobic digestion and requires a smaller capital expenditure. It is also aesthetically more acceptable in that the resultant sludge is suitable for disposal by land spreading or landfill. Other advantages to the aerobic stabilization process include:

WHICH ONE IS THE BEST????

Chemical Treatment

inorganic conditioners
organic conditioners
recovery fertilizer

Biological Treatment

aerobic
anaerobic
enzymes
composting

Physical Treatment

freezing
heat
filtration
thickening

Ultimate Disposal

land spreading
strip mines
ocean disposal
incineration
land fill
dry fertilizer

Tons and Tons of Sludge

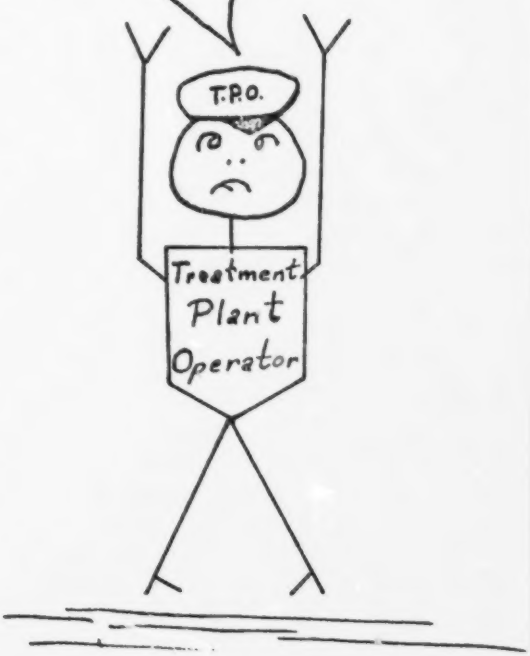

FIG. 2

DEWATERING ALTERNATIVES

1) reduction in pathogenic microorganisms: 2) grease removal; and 3) a supernatant which requires little treatment. Important parameters in this process are air requirements, time of aeration, sludge age, and filterability, settleability, and drainability of the product. The disadvantages include high operating costs and unclear design criteria. Sludge filterability by rotary vacuum filter and settleability were not improved with aerobic stabilization in studies conducted by us and others. The literature is not clear on this subject.

Significant reductions in volatile solids, grease, and pathogenic microorganisms together with the production of a highly nitrified effluent were achieved in our past studies performed with waste activated sludge from the Colerain Heights Sewage Treatment Plant of the Metropolitan Sanitary District of Cincinnati. The use of pure oxygen for aerobic stabilization was studied by the Ultimate Disposal Research Program in Cincinnati and found not to offer any advantage over the use of air. While the process in the past has been designed for a long retention-time of 15-30 days, our work as well as others indicates that the biggest part of the job is completed in only 5 days. As an example: 98% of the reduction in respiration rate achievable in 21 days was accomplished in the first 5 days. Further, better than 50% of the reduction in such parameters as suspended solids and COD that would be achieved

in 20 days was accomplished in 5 days. This process is extensively being used in the State of Pennsylvania where they are designing the process for a short detention time. The Chicago Pump "Rapid Bloc" process is designed for a 5-day retention for a sludge concentration of 12,000 ppm. It is sized on the basis of 1.4 cu.ft. per capita. Other systems will allow more. Suggested digester loads range from 0.1 to 0.2 lbs. VSS/lb.solids/day.

ANAEROBIC DIGESTION

Anaerobic digestion is the biological conversion of organic matter in the absence of molecular oxygen to simple compounds. End products of the conversion are chiefly methane and carbon dioxide.[8] The methane generated has frequently been used for heating and to run generators. Control of the digesters is often difficult because of the sensitivity of microorganisms to toxicity, and capital costs for facility construction and heating provision are high. Typically a 50% reduction in volatile solids will be attained. The supernatant presents a treatment problem, since it is usually high in BOD and solids and cannot be allowed to lead to the deterioration of the effluent quality. Characteristically the design criteria and sizing of a heated anaerobic digester are to allow from 3 to 5 cu.ft.per capita. The larger figure applies to biological sludges. Said another way, this might be stated as

from .02 to .15 lbs. applied per day per cubic ft.

COMPOSTING

Composting has received attention because of its relative versatility in solid waste treatment. Organic, industrial, agricultural as well as domestic sludges have been examined. The degree of interest in composting in this country, as well as abroad, is dwindling for economic reasons.[9] The usual reason for failure of composting plants is the inability to develop a market for the compost.

CHEMICAL METHODS

Numerous methods for chemically treating and conditioning sludges to assure satisfactory dewatering are being explored to assess their effects in the preparation of sludge for filtration, centrifugation, flotation, and gravity thickening. Inorganic chemicals widely used in the past include: lime, ferric chloride, copperas ($FeSO_4$), chlorinated copperas ($Fe_2(SO_4)_3$), aluminum chlorohydrate, and alum. Use of polyelectrolytes, a relatively new and rapid chemical development, is growing in popularity for the conditioning of sludge. Required dosages of chemicals and polyelectrolytes are thought to be a function of solids content, alkalinity, type of sludge and other factors. In order to significantly improve the sludge thickening obtainable with either a gravity or flotation process, typically from 10 to 20 pounds of a polyelectrolyte is required per ton of dry solids. In the vacuum filtration

of sludge, two-fold increases in productivity may be achieved by a) adding approximately 9 percent lime and 2 percent ferric chloride (on a dry weight basis) for raw primary sludge; b) adding approximately 12 percent lime and 4 percent ferric chloride for a digested raw sludge and, c) adding approximately 20 percent lime and 6 percent ferric chloride for a digested combination of raw and digested sludges. If polyelectrolytes have been used to condition the combination digested, approximately .5 to 2 percent would be required. The quantity of chemical required in centrifugation for production of low cake moisture and high quality centrate (low solids) are similar to those required for good filter productivity. This might be anywhere from .5 to 2.0 percent polyelectrolyte on a dry solids basis.

The Ultimate Disposal Research Program recently made studies into the chemical conditioning of activated sludge for vacuum filtration. Five inorganic and twenty-three organic sludge conditioners were evaluated using the Buchner Funnel[10] and/or filter leaf test[11] to determine their effect on the vacuum filtration of sludge. The Buchner Funnel Test gives a measure of a sludge's resistance to filtration, whereas the filter leaf test gives the expected sludge production rate on a rotary vacuum filter in pounds of sludge solids per square foot per hour. Surprisingly, the most effective inorganic conditioner was found to be sludge in-

cinerator ash. Sludge ash is available on site, free of charge, if the filtered sludge is incinerated. At all levels of addition of ash an improvement in filterability was noted. An almost linear relationship existed between the filter yield and the quantity of ash added. At a maximum dosage of 5 parts ash to one part activated sludge, filterability was improved by a factor of 5. Primary, digested, and trickling filter sludges showed similar improvement with ash. Polyelectrolytes gave improvements in filtration from 0 to fourfold, although the cost at fourfold is prohibitive.

SLUDGE STABILIZATION BY LIME AND SULFUR DIOXIDE ADDITION

A revolutionary and, from our point of view, economically promising idea was stabilizing sludge with lime or sulfur dioxide in preference to biological digestion. This treatment would be used prior to land spreading of sludge or placing it on drying beds. We performed basic studies to determine the effect of elevating the pH of a sludge with lime to 11.0 and maintaining it there for a period of 24 hours. Similarly, the effect on sludge by adding small quantities of sulfur dioxide for the purpose of stabilizing was evaluated. Both primary and activated sludges were studied. Success was expected with these processes because the odor-producing, and probably the pathogenic organisms would be killed. In the case of lime at pH 11, both the elevated pH and the production

of ammonia in the sludge are responsible for destruction of the organisms, while in the other instance the sulfur dioxide itself is toxic to the organisms. In all instances, obnoxious odors and colors were almost instantly eliminated by treatment either with lime or sulfur dioxide.

PRODUCT RECOVERY

The recovery of valuable products from sludge, and its use as an animal-diet supplement have been investigated.[12,13,14] The problems with all such methods are the costs of recovery and the finding of a market. In some areas, such as Milwaukee and Chicago, dried activated sludge is bagged and sold as a fertilizer or soil conditioner. Milwaukee's success is attributed to a substantial selling effort, an activity which most municipal authorities are unwilling to undertake. An advantage of drying is the death of pathogens. In one instance the organic matter in sludge was hydrolyzed by heat treatment using sulfur dioxide as a catalyst. (Bouthilet and Dean, 1970[14]). The resulting liquor had a high amino acid content which after rat feeding itself was shown to be a good feed supplement that would enhance food usage. An early evaluation of this research work indicates a good profit potential for this process.

An industry where recovery has potential is the food and beverage industry. However, the fact remains that each company must evaluate its own unique situation, the alternatives open to it and the market for any materials recovered.

PHYSICAL PROCESSES

FREEZING

Several approaches are being taken with physical processes. The freezing of water treatment plant sludges is practiced in Europe, but is not beyond the pilot stage in the United States.[15,16] Both artificial and natural freezing are employed. Freezing is found to greatly enhance the ability of the sludge to be dewatered. Under present conditions, however, natural freezing with its limitations is being looked upon with much more favor than are the artificial processes because of their poor economics.

Natural secondary effluents obtained from local treatment plants and synthetic effluents were employed in a study by the Ultimate Disposal Research Program as a process for improving their dewaterability.[17] Snow cover, the available environment, completeness of freezing, sludge depth, method of application, and organic content were found to be important variables. Sludge after complete freezing was found, upon thawing, to rapidly settle and filter with a magnitude of improvement of 3 to 4 times. Supernatant quality was relatively good. In actual practice, a large surface-to-volume ratio was found desirable along with provision for keeping the surface free of snow. Since complete freezing is essential, the application of thin layers was found to be a good approach.

HEAT

Drying Beds

Heat as a method of physically treating sludge is employed in a number of processes.[18] One of the more common methods of handling sludge is to pump it out onto sand drying beds, where the excess water is removed by percolation and evaporation. The sludge has usually been anaerobically digested before being spread on beds. Important factors are depth of applied solids, concentration, and media used. As you can see, this method requires considerable land area. The finished sludge usually contains 50-60% water. This is probably the most common method of sludge dewatering after digestion. With properly prepared sandbeds, drainage will remove the larger portion of the water in 7 to 10 days. Typically the bed will contain from 12 to 15 inches of sand, underlying gravel and an underdrain which is usually made from farm tile that slopes toward an outlet drain. In sizing the bed one usually allows about 1 square foot per capita or approximately 27 pounds dry solids per square foot per year for digested raw sludge and 3 square feet per capita or 15 pounds of dry solids per square foot per year for digested-combined raw and activated sludge. A critical factor in determining the time for sludge drying is the location of the treatment plant with regards to such factors as solar energy or rainfall.

Zimmerman Process

The Zimmerman Process also involves heat. In this process, the organic matter in sludge is oxidized by contacting air and sludge in a reaction vessel under sufficient temperature and pressure. Operating conditions range from 500° to 700°F. and 1200 to 1800 psig. This process may not require external power to sustain combustion once it is started, if the solids content is sufficiently high. Up to 90% of the organic matter can be removed.[19] A large problem is treatment of the liquor produced by the process. The Zimmerman Process can be run at lower temperatures and pressures where it is essentially a sludge conditioning system. The supernatant still requires further treatment, while the sludge can be easily dewatered. Zimpro Division of Sterling Drug markets the process and handles the design.

Porteous Process

The Porteous Process involves the pressure cooking of sludge at 370°F. The sludge is hydrolyzed, living cells and spores are killed, and filtration is made easier.[20] However, soluble nutrients and BOD are released into the supernatant. This material needs further treatment. The sludge after treatment is readily dewatered. This process is offered under the name of Porteous by B.S.P. Corporation. The Farrar Process which is similar with the exception that the final heating is done by indirect steam is marketed by Dorr Oliver.

SLUDGE DEWATERING

Sludge thickening or concentrating can be done by a number of methods. These include vacuum filtration, pressure filtration, centrifugation, gravity, and flotation.

VACUUM FILTRATION

Vacuum filtration is practiced on raw sludge, digested sludge, chemical sludges, and activated sludge. Typically, the filter consists of a cylindrical revolving drum 4 to 8 feet in diameter which is partially submerged in a tank of sludge. The drum is divided into sections which may be placed under positive or negative pressure. As the drum revolves, sludge is picked up by the vacuum. Excess water is sucked into the center of the drum, leaving a sludge cake on the filter cloth. The sludge is removed from the filter by low pressure air and a shear plate. While the moisture content of the raw sludge may range between 90 and 97%, the moisture content of the sludge cake will range between 70 and 80%. Typical yields for a: a) a raw primary sludge are 3 to 6 pounds of solids per square foot per hour, b) a digested primary sludge are 2 to 5 pounds of solids per square foot per hour, and c) an undigested activated sludge are less than 1 pound of solids per square foot per hour. Each sludge presents a special situation. You must determine the optimum cycle time, % submergence, vacuum, and media to give you the desired filter productivity and cake moisture. Chemicals are usually a considerable aid.

Filter presses are widely used in Europe, and improvements on them have been made in recent years. The solids content of the product is about 40 to 60%.[21] Plate and frame filter presses are starting to receive consideration in this country, however, their only present employment is for demonstration.

CENTRIFUGATION

Centrifugation is a method for the concentration of sludge.

All centrifuges are used in sludge dewatering sedimentation type units.

There are three basic types of units. They are the disc, conveyor, and basket centrifuges. The disc unit typically operates around 6500 G-forces and can be used for activated and chemical sludges once they have been screened. The conveyor or scroll unit, which is the most popular in wastewater treatment, has adjustable weirs for the bowl or pond depth. It is not recommended for alum or activated sludge but is good for raw and digested sludge. It operates at approximately 3000 G-forces. The basket centrifuge has a vertical bowl and operates between 1300 and 1600 G's. Solids are discharged by a scraper and tube coming down into the bowl. This unit is good for activated and chemical sludges.

In the conveyor centrifuge, sludge slurry enters a rotating bowl through a stationary feed pipe extending into

the hollow shaft of the rotating screw conveyor and is then distributed through ports into a pool within the rotating bowl. It is possible to vary the depth of this liquid pool. While the liquid is flowing through the cylindrical section towards the overflow devices, finer and finer solids are settled centrifugally to the rotating bowl wall. The conveyor pushes the solids into the conical and out the end of the machine. Water drains back into the pool under the influence of G-forces, where it is removed by a skimming device or flows over a weir.

Solids concentration is of the same order that you get with a vacuum filter. To obtain a high quality centrate, chemical addition is required. Reported centrifuge performances are erratic and some pilot scale tests should have been performed prior to purchase of a machine. Performance of a given centrifuge is a function of type of sludge, sludge thruput, solids content, pool depth, and rpm. The major manufacturers are the Bird Company, Sharples, and Dorr Oliver.

The basket and disc centrifuges are now beginning to find more of a place in the wastewater treatment industry as the use of each piece of equipment is more clearly defined.

FLOTATION

Flotation is another method for concentrating solids. Rising gas bubbles are used to increase the buoyancy of

solid particles. Five methods have been suggested for this. They are: 1) Dispersed air flotation; 2) Dissolved air-pressure flotation; 3) Dissolved air-vacuum flotation; 4) Biological flotation: and 5) Electrolytic gas flotation. Dissolved air-pressure flotation is the most popular and is used in the thickening of activated sludge. It has been thickened to 4% with this method.[23]

Important process variables are pressure, recycle ratio, detention period, air-to-solids ratio, and the use of chemical aids. Type sludge and solids content are of course very important. Normally about 0.03 ft^3/ft^2/min of air is supplied or about 0.02 pounds of air/pound of solids. A common recycle rate is about 40%. A loading rate might be 13.5 pounds of activated sludge solids/ft^2/day.

OTHER DEWATERING TECHNIQUES

Gravity sludge thickening, using clarifiers containing a mechanism with pickets, has been successful.[24]

Other methods for concentrating sludge include the "Roto Plug" device and vibrating screens.

ULTIMATE DISPOSAL

Section VI, Part A under Guidelines for Design, of the Federal Guidelines, Design, Operation and Maintenance of Waste Water Treatment Facilities,[24A] is entitled, "Ultimate Disposal of

Sludge and Solids." It reads as follows:

"a. Provision for ultimate disposal of sludge must be clearly indicated and must be in accordance with interstate, State, and FWQA requirements. It is not sufficient merely to indicate such processes as drying beds, vacuum filters, or incinerators, without also describing the method to be used for final disposal of the sludge cake or sludge residues.

b. The method of final disposal must not result in any significant degradation of surface or ground water, air, or land resources. If there is a choice, the method chosen must be that having the least impact on the environment.

c. No sludge residues, grit, ash, or other solids may be discharged into the receiving waters or plant effluent. The disposal of any sludge to ocean waters is not recommended.

d. Disposal of raw sludge to fresh or marine waters or by spreading and tilling on land will not be approved.

e. Sludge elutriation is not considered desirable and will not be approved without adequate safeguards."

LAGOONING

Lagooning or landfill is frequently employed as a means of ultimate disposal. Lagoons can be used as anaerobic digesters, being mindful of the aesthetic problems; as an evaporation pond, where the sludge is allowed to dry and then be removed; or as permanent lagoons or landfills where an area is filled to a desired depth with sludge and allowed to dry. Area requirements and management are important.

LAND SPREADING

Digested and aerobically stabilized sludge may be used as fertilizer or soil supplement. Raw sludge presents health and nuisance problems. Transportation costs must be considered.

Fertilizer Value of Bio-Oxidation Sludge

Nitrogen	1-5%
Phosphate	1-3%
Potash	0.1 - 0.3%

Anaerobic digestion will reduce these values 40-50%.

The main advantage to land spreading is economy in most areas. It is an ultimate method since there is no ash to dispose of. When properly done, it is a way of utilizing the nutrients, water, and organic material to promote soil productivity and crop yields, and it is nuisance free.

Disadvantages are when improperly done, nuisance conditions are created, health hazards are present, accumulation of toxic metals may result and nitrate contamination of ground water can occur.

The quantity of sludge that may be spread is a function of the soil characteristics, climate, land use or intended crop, and the type and solids content of the sludge. Two major uses of land spreading of sludge at present are to reclaim low quality land and improve soil and crop productivity.

Typical application rates for sludge are for a corn field, 10 to 30 tons of solids/acre/year and for a strip mine, about 1000 tons of solids/acre/year. Again each situation should be evaluated for its own merits.

INCINERATION

Incineration in either a multiple hearth or a fluidized bed furnace is a method of ultimate disposal in which the sludge, either raw or digested, is burned and reduced to combustion gases or ash. Multiple hearth furnaces range in capcity from 200 to 8,000 #/hr. of dried sludge, and operate at 1700°F. The Multiple Hearth Furnace consists of a refractory-lined circular steel shell with refractory hearths, which lie one above the other. Sludge is fed through the furnace roof by a screw feeder or belt and flopgate. A rotating air-cooled central shaft with air-cooled rabble arms and teeth plows the sludge across the top hearth to drop holes. It falls to the next hearth and then the next until ash discharges at the bottom. B.S.P. and Nichols are major manufacturers of Multiple Hearth Furnaces and can assist in designing.

In a fluidized bed furnace, the mechanically dewatered sludge is fed into a fluidized sand bed that is supported by air at 3.5 to 5.0 psi. Normally, sludge solids are degritted before dewatering to prevent equipment wear and to obtain a sludge with the highest possible volatile content. The fluid bed reactor is a single chamber unit in which moisture evaporation and combustion of organics takes place simultaneously under

oxidizing conditions at 1,400 to 1,500°F.[28] Major manufacturers of fluidized bed furnaces are Dorr Oliver and Copeland Corporations.

When properly operated, sludge incinerators are relatively air pollution free compared to a solid waste incinerator. Consideration of the quantity of air pollutants discharged must be given, however.

UNIQUE METHODS FOR HANDLING SLUDGES

It is necessary in an area such as ours which is responsible for a major cost portion of treating waste water to finance a few projects which seemingly are far out in the hope that by chance they will yield a result which would greatly cut the cost of sludge handling. Some of the projects which fall in this category and which are supported by the FWQA and monitored by the Ultimate Disposal Research Program are listed below together with their level of financing.

Company Receiving Grant or Contract	Project Financed	Level of Financing
Rocketdyne, Canoga Park, California	Electro-osmosis as a Technique for Sewage Sludge Dewatering	$ 79,966
Clemson University Clemson, South Carolina	Fermentation of Sewage Sludges to Useful Products	$ 89,000
Aerojet-General Corp. El-Monte, California	Biological Methods of Sludge Dewatering (Enzymes)	$ 93,000

OTHER TECHNIQUES

FWQA studies are currently underway on strip mine filling with sludge, spreading of sludge on land, acceptability of sludge by farmers.[25,26,27]

Coastal cities often dispose of raw sludge through release into the ocean directly from outfalls. To date, it has been impossible to make a single set of standards, but we do know that some coastal areas have been polluted. Preferably, sludge should be stabilized by some method prior to ocean discharge.

Deep well injection of sludge should be practiced only with extreme care. Consideration must be given to pollution of nearby drinking water sources, prior stabilization of the sludge, opening of underground channels by pressure injection, and possible production of earth quakes.

USUAL SLUDGE TREATMENT PROCESS COMBINATIONS

The most common process combinations employed in the handling and disposal of sludge can be listed as follows:

1. At the sewage treatment plant--anaerobic digestion followed by sand bed dewatering. For many treatment plants, this is the least costly method.
2. Direct discharge to lagoons. This is most commonly used by industry.

3. Anaerobic digestion followed by pipeline transportation to the ocean or land reclamation areas. This is by far the least expensive method.
4. Digestion followed by barging for disposal at sea is economical. This method is most commonly used by near coastal cities, with access to the ocean.

Mechanical dewatering of sludge, incineration, and land disposal of sludge are increasing in popularity.

Costs

Process	Costs	Source
1. Digestion + Sand Bed Dewatering	$25/ton	Burd[29]
2. Pipelining to Sea or Land Disposal	$3-7/ton	Cleveland[30]
3. Barging to Sea	$9/ton	New York[31]
4. Digestion and Reclamation of Farm Land	$15/ton	Chicago[32]
5. Digestion and Reclamation of Strip Mine	$16/ton	"
6. Drying and Selling as Fertilizer (net)	$45/ton	"
7. Digesting and Lagooning	$49/ton	"
8. Wet Air Oxidation (Zimpro)	$50/ton	"
9. Dewatering and Incineration	$57/ton	"

SUMMARY AND CONCLUSIONS

The solving of any waste problem requires first that attention be given to good housekeeping to see if some waste sources can be reduced and second that consideration be given to reuse of waste components.

In any sludge disposal problem, it is essential to consider the character of the sludge, the availability of land, the suitability of the sludge for disposal to a waterway, the possible use of the sludge as a fertilizer, and capital and operating costs.

This paper has attempted to present the presently available methods and their costs and some of those which are being researched for disposal of sludge solids. Treatment plant space, nuisance problems, economics, and health are involved.

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